PB-217 948

EUTROPHICATION OF LAKES

Charles F. Powers

Federal Water Quality Administration
Corvallis, Oregon

9 April 1970

DISTRIBUTED BY:

NTIS

National Technical Information Service
U. S. DEPARTMENT OF COMMERCE
5285 Port Royal Road, Springfield Va. 22151

E28

PB 217 948

Man and Aquatic Communities

Seminar Conducted by

WATER RESOURCES RESEARCH INSTITUTE

Oregon State University

Library
Pacific Northwest Water Laboratory
200 South 35th Street
Corvallis, Oregon 97330

Spring Quarter 1970

GOVERNING BOARD

FRED J. BURGESS, Acting Dean, School of Engineering
CARL H. STOLTENBERG, Dean, School of Forestry
G. BURTON WOOD, Director, Agricultural Experiment Station
ROBERT M. ALEXANDER, Director of the Institute

GEORGE W. BROWN
FRANK D. SCHAUMBURG
GERALD E. DAVIS

ROYAL H. BROOKS
FRANK J. BARRY
HERBERT H. STOEVENER

Reproduced by
NATIONAL TECHNICAL
INFORMATION SERVICE
U S Department of Commerce
Springfield VA 22151

July 1970

7

Presented April 9, 1970 by CHARLES F. POWERS, National Eutrophication Research Program, Pacific Northwest Water Laboratory, Federal Water Quality Administration, Corvallis, Oregon.

Eutrophication of Lakes

The aging of a lake is a natural process. In this sense it is much like a human being: a lake is born, grows old, and, in many cases, dies. It is this maturation process of a lake that is called eutrophication, and it leads to some of the most serious water quality problems we face today.

Lakes are formed, or born, in a number of ways. In the United States the great majority of lakes were brought into being by the continental glaciers. The many lakes of the upper midwest, for example, are Pleistocene in origin. Many of these lakes are so-called "ice block" lakes, created by masses of ice which formed depressions in the earth that eventually filled with melt water. Lakes are also formed by landslides, cut-off bends of rivers (oxbows), in craters of extinct volcanoes, and other means, but most of the natural lakes which concern us are glacial.

A newly-formed glacial lake is of the type known as oligotrophic; the name derives from the Greek and means essentially "poorly nourished." The young lake is poorly nourished because the concentrations of dissolved nutrient materials in its waters are low.

There has not yet been time for such materials as phosphorus, nitrogen, carbon, and so forth, essential to the production of biological material, to be carried in from the surrounding watershed. Algal growths in oligotrophic lakes are small; the algae that do occur are the single-celled diatoms which do not form objectionable nuisance blooms. Since production is low, there is relatively little particulate matter in suspension and the water is normally of a high degree of transparency.

Also, because there is little plant and animal respiration in such a lake, the water is well oxygenated at all depths in all seasons of the year. The fish populations of oligotrophic lakes are made up of cold-water forms - trout, salmon, whitefish, and the like, which require low temperatures and high oxygen levels.

An oligotrophic lake, then, is a lake containing high quality water and is suited to a variety of uses; it is a good multi-purpose lake.

NUTRIENTS AND PRODUCTION

Under natural conditions nutrients will be added to the lake through runoff and leaching from the soils and rocks of the surrounding drainage basin. The result is increased concentration of minerals and other materials essential to the production of plant material, principally algal forms. Progressive nutrient buildup is accompanied by increased species diversity of the phytoplankton and increase in the total algal biomass.

As eutrophication proceeds, however, diversity will decrease and the flora will tend to be dominated by a few species of green and blue-green algae, with the blue-greens in particular appearing in nuisance masses. Such genera as Aphanizomenon, Anabena, and Microcystis become common.

The progressive enrichment and increased biological production of the lake are accompanied by a gradual filling in of the lake basin by inflowing sediment and by the remains of weeds, algae, and other organisms. This decrease in depth leads to an increase in average lake temperature. The warmer waters, coupled with the greatly increased oxygen demand resulting from bacterial breakdown of decaying organic matter and the respiration of increased numbers of other organisms, result in deficits of dissolved oxygen in the deeper waters, especially in the summer and early fall months.

The lake, then, gradually changes, through natural aging, from a deep, clear, cold, well-oxygenated body of low productivity to a relatively shallow, warm, turbid, highly productive lake whose water is of greatly decreased quality and of limited usability. The lake has evolved from an oligotrophic to a eutrophic situation. Eutrophic, also from the Greek, means "well-nourished." Such a lake will no longer support the oligotrophic cold water fauna. Trout, whitefish, and like forms will have disappeared, to be replaced by "warm water" forms.

In many cases, where the nutrient supply from the drainage basin is adequate, eutrophication may continue until the lake is completely filled in, and natural succession will result in the establishment of purely terrestrial conditions.

Many of our Pleistocene lakes are still in a condition of oligotrophy. These are lakes in which the accumulation of nutrients has proceeded very slowly, either because the lakes are large and deep, the surrounding land is poor in nutrients, the drainage basin is quite small, or a combination of such factors.

Large numbers of lakes, however, have eutrophied to various degrees. This may be due principally to naturally fertile drainage basins, or, relatively recently, to induced fertility associated with increased human population.

THE ROLE OF MAN

The role of man in the eutrophication process has been recognized by limnologists for some time, and in recent years has received a great deal of attention. Human waste disposal may greatly increase the rate of flow of nutrients into lakes and thereby profoundly affect the eutrophication process. This phenomenon is usually referred to as accelerated or "cultural" eutrophication. Conventionally treated, as well as untreated, human wastes contain large amounts of algal growth stimulants, and many lakes receiving such effluents are currently exhibiting symptoms of rapidly increased deterioration. Massive algal blooms are one of the most serious and objectionable of these symptoms.

The classical view of the eutrophication process has been that it is an inevitable, irreversible process that, having advanced to any given stage, becomes a condition that may at best be slowed down but can neither be stopped nor reversed. Recent research, however, has modified this viewpoint and has resulted in increased optimism as to the possibilities of not only halting the deterioration of lakes, but even restoring at least some to their earlier, less eutrophic states.

It is evident now that, under natural conditions, the nutrient supply from the soils and rocks of the drainage basin will not necessarily continue unabated (continued leaching and erosion depletes the supply), and the lake may actually, after achieving its peak of eutrophy, become less productive with continued time as the nutrients are washed out or otherwise removed from circulation.

In addition, evidence now indicates that the large quantities of nutrients commonly found in the sediments of lakes are not constantly recycled and that there is, with time, a gradual net loss of nutrients to the sediments as they are progressively covered up. The bulk of the evidence, then, is that if we can significantly decrease the nutrient supply, we have a fighting chance of restoring the lake to at least some semblance of its former condition.

PRACTICAL RESEARCH APPROACHES

The National Eutrophication Research Program (NERP) of the Federal Water Quality Administration has the responsibility for conducting research directed toward halting and preventing eutrophication of our waters. The National headquarters for these research activities is located in the Pacific Northwest Water Laboratory at Corvallis, Oregon.

Both preventive and remedial procedures are being investigated and developed. In considering avenues of approach, four general possibilities present themselves: (1) Ecological Control; (2) Mechanical Control; (3) Chemical Control; and (4) Biological Control. Of these possibilities ecological control represents methods which are more preventive, while the others represent methods which are either remedial or palliative.

The major emphasis, therefore, is on ecological control with the prime objective to keep the water environment at a preferred low level of fertility and production. This method is less likely than the other approaches to destroy those conditions which are desirable and is likely to have more lasting effects.

The most obvious approach to ecological control is to prevent or decrease the nutrient input to the water. Most of the nutrient input comes from municipal sewage, urban and rural runoff, soil erosion, agricultural activities, industries, and precipitation. Nutrient control can often be accomplished by diversion of nutrient-containing waters, especially sewage effluents, away from the lake.

Another method, of course, is to strip sewage effluents of their nutrients, especially nitrogen and phosphorus, by tertiary treatment processes. For the past two years NERP has operated a pilot scale chemical tertiary treatment plant at Ely, Minnesota, on the shores of Shagawa Lake. This 2-1/2 square mile lake receives treated sewage from the city and this sewage accounts for 80% of all phosphorus entering the lake.

Experience with the pilot plant has shown that removal of this phosphorus from the municipal effluent should result in control of nuisance algal conditions which occur in the lake. It is, therefore, planned to initiate a full-scale treatment program. Details in the pattern of recovery of the lake as it responds to phosphorus starvation will then be studied closely.

Such knowledge will form the basis for predicting how other lakes will respond to similar control programs. Facts on eutrophication of Shagawa Lake will be incorporated into a mathematical model in order to predict the pattern of recovery.

After a lake has accumulated large amounts of nutrients, curtailing further input may not in itself be sufficient to improve or restore the lake to an acceptable condition, particularly if dilution by flow-through is small. NERP, therefore, is developing and evaluating techniques for either removing or rendering unavailable nutrients for algal and aquatic weed growth. Several possibilities are under study: (1) harvesting of algae; (2) harvesting of water weeds; (3) dredging out nutrient-rich sediments; and (4) nutrient inactivation.

A NUMBER OF PROJECTS

Present methods for harvesting algae are generally inefficient and costly. Present efforts are supported entirely by grants and contracts, and are aimed at developing efficient harvesting equipment and identifying chemical components of blue-green algae that may be useful as pharaceuticals.

At Detroit Lakes, Minnesota, a project is underway to determine the quantity of nutrients that can be removed from a lake through mechanical harvesting of rooted aquatic plants. Baseline data are being gathered on the ecology of the lake and its tributaries. This will permit an assessment of eutrophication reversal when the actual harvesting is initiated this summer. Mathematical modeling will also be employed in predicting and establishing the rate and extent of lake improvement.

As mentioned earlier, substantial quantities of nutrients are tied up in lake sediments. This potential source of nutrients may be of particular importance in shallow, non-stratifying lakes. This may be true in shallow, eutrophic Upper Klamath Lake, for example, where our studies indicate that agitation of the sediment by waves and currents causes transfer of nutrients to the overlying water with resulting stimulation of algal growth. The sediment-water interchange problem is being approached along three lines: (1) learning the fundamental nature of the recycling mechanism; (2) developing procedures to prevent recycling; and (3) dredging out sediments.

Results of laboratory studies at Corvallis suggest that chemical treatment of a eutrophic lake with rare earths or aluminum compounds will precipitate out nutrients and slow down their recycling from the sediments. Candidate lakes are now being selected for full-scale nutrient inactivation and dredging studies and actual treatment will proceed when funds are available.

The annual temperature-chemical cycle which takes place in lakes and reservoirs due to seasonal climatic variation greatly affects the characteristics of the water. Algae tend to proliferate in the warmer upper layers and eventually die, sink to the bottom, and decay, thus creating a high oxygen demand there. The dissolved oxygen is depleted and, if the lake is in a stratified condition, there is no replenishment of oxygen in the bottom waters, or hypolimnion.

Experimental destratification by aeration in a small pond near Corvallis this past summer virtually eliminated this condition. Further, the usual crop of blue-green algae did not appear. Aeration is a promising tool in the fight to rehabilitate lakes.

Personnel at our Corvallis laboratory are also looking into the significance of rain and snow as sources of nutrients. Analyses of samples collected in and around Oregon show that they frequently contain sufficient nitrogen, phosphorus and micro-nutrients to stimulate algal growth.

The use of bioassay procedures for detecting increased enrichment in the aquatic environment holds considerable promise. In many cases these bioassays appear to be more sensitive than chemical determinations. Such assays, however, would have much more value with respect to comparing data among laboratories and geographic areas if they were standardized. NERP, with industry and university cooperation, is working to develop these vitally needed standard procedures to assay algal growth possibilities in waters of various kinds.

It should be pointed out that work on these various areas of research, sponsored by FWQA grants and contracts, is being carried on at universities and other research centers throughout the country. These extramural investigations constitute a most critical portion of the overall NERP program, and permit studies of many facets of eutrophication-related phenomena which otherwise could not be pursued.

SUMMARY

Most lakes appear to experience a physiological aging process known as eutrophication.

Essentially, this process comprises increased nutrient concentration and consequent increased biological production. Newly-formed lakes, or lakes situated in non-fertile locations, are poor in dissolved nutrients and relatively unproductive, and are known as oligotrophic lakes. With time, gradual enrichment from the watershed may result in production of large quantities of organic matter, especially undesirable algae; oxygen deficits; and a gradual filling-in of the lake.

The change is therefore from oligotrophic to eutrophic. The introduction of the effluents of human populations may greatly increase the eutrophication rate, and the quality of many lakes has been seriously impaired through this accelerated or "cultural" eutrophication.

The research activities of the National Eutrophication Research Program are aimed at the development of methods for the control and alleviation of accelerated eutrophication and include both applied and fundamental studies. The more applied investigations relate to the limitation and removal of plant nutrients, and to the elimination and control of algae and waterweeds.

The applied investigations are supported by more fundamental studies relating to the metabolism and the physiological requirements of algae and other aquatics associated with eutrophic conditions as well as to the development and evaluation of assay procedures for detecting increased enrichment and predicting its effects on the aquatic environment.